Home of the 1996 Olympic Village

Georgia Tech Research Institute

13 October 1997

Reference: Contract No. N00014-96-1-0175

Subject: Performance Technical Letter Report
CDRL No. 2, Letter Report No. 2
Covering the Period 16 October 1996 through 15 October 1997

Dear Sir:

This letter Report is submitted in response to Contract N00014-96-1-0175, Contract Deliverable Requirements List (CDRL) No. 2, Report No. 2. The enclosed letter report covers the period 16 October 1996 through 15 October 1997.

If you have any questions or comments, please contact me at (404) 657-0431.

Sincerely,

Gary W. Caille

Gary Caille

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Annual Progress Report for:
Determination of Acoustic Parameters of Navy Coatings
(formerly titled: "In-Situ Determination of Coating Material Acoustic Properties)

Principal Investigators: Jacek Jarzynski, Gary Caille, and John Doane

1. Motivation

Present hull treatment properties are highly dependent on the local temperature and pressure conditions. Their properties and functionality are also highly dependent on the chemical mixing, i.e., mixture stoichiometry, which occurs during the pour-in-place application of the coating to the hull. Presently, there is a deficiency in the manner by which the material properties of Special Hull Treatments (SHT) are determined. Today, core or pour samples are taken from the applied SHT and sent to a laboratory for evaluation of its material properties. For core samples, the technique suffers from being destructive, limited to small sample areas, and time consuming since the cored region must be repaired. If pour samples are used, again the technique is limited to almost point sample and does not reflect the effect of hull application. In both sample methods there is a time delay in analysis which results in there being little or no impact on the application process.

There are additional related problems such as poor surface adhesion to the hull and poor seam bonding which could have significant effects on the physical integrity of the coating. As these treatments become integral parts of systems, e.g., CAVES, the presence of air bubbles and poor local stoichiometry such as polymer inclusions may cause unacceptable system degradation. None of these real world quality control issues is satisfactorily checked during the application process.

Finally, NAVSEA 92RC has been tasked with evaluating a large number of commercially available coatings. Evaluation of coating performance should be completed in a water environment (since some materials have properties which are dependent on humidity) over relevant temperature and pressure conditions.

2. Technical Objective

Currently there are three technical objectives:

(1) Determination of the complex elastic moduli of the material over a large sample of the material. These moduli are a direct indication of the quality control of the SHT production and application. They are also fundamental indicators of the acoustic performance of the treatment. As part of this measurement task, the feasibility of applying this technique to the shipyard quality assurance environment and to a

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laboratory scenario for investigation and characterization of commercial coating supplied by NAVSEA 92RC1 should be investigated.

(2) Adaptation of the same system for detection of localized inclusions or discontinuities. It is believed that this technique could be used for analysis of seam integrity also. It is thought that this technique could be expanded for use on-site in a shipyard during application of the coating. This would allow for more timely analysis of the performance of the coating over a greater portion of the total surface of the vessel.

(3) Extension of the above technique to make approximate measurements of the reflection coefficient of stress waves at the coating-hull interface. This reflection coefficient should be a direct measure of the local adhesion of the coating to the hull.

3. Technical Approach

Development of a system for achieving the above technical objectives is underway. The system is a fiber-optic based measurement and analysis package that utilizes surface velocity measurements and wave propagation physics to determine characteristics of a region of SHT. The measurement device is a Laser Doppler Vibrometer (LDV), capable of measuring the in-plane and out-of-plane particle velocity at a point on the surface of the SHT. The measurement location can be easily and quickly changed so that an array of surface velocity data can be collected in a short period of time. To investigate the condition of the SHT, namely measure the complex moduli and detect inclusions, a transient sound wave is generated at a point on the surface by a shaker, and this wave propagates into a region around the drive location. The LDV is then used to measure the resulting surface velocity at a number of prescribed locations on the SHT in the vicinity of the source. Analysis of the motion at the surface leads to determination of wave propagation speeds, attenuation factors, and presence of inclusions through comparison with physics-based models and baseline reference data. See figure 1 for illustration.

4. Summary of Prior and Current Year's Work

<u>February 1996 - April 1997</u>

During this period significant amounts of data were taken on the 30 inch by 30 inch panel and signal processing efforts initiated. The panel was a 2 inch thick sheet of SHT bonded to a 2 inch thick steel plate. Figure 2 is a picture of the LDV experimental setup. The signal processing was aimed at making rough estimates of wave speeds and qualitative characterization of the sample response, and thus simple cross-correlation techniques were used, which produced wave speed values within 10 percent of the values arrived at by conventional methods. Simultaneously, model development was

initiated to improve understanding of wave propagation in the panel, which is to be used eventually in conjunction with signal analysis to extract material properties from the data. This modeling effort centers around a physics-based model, Weaver's "Transient ultrasonic waves in a viscoelastic plate: Theory" (JASA, 1989). The exact model of Weaver will be used (1) to develop a physical understanding of the generation and propagation of transient waves both in the near field and far field of the shaker,

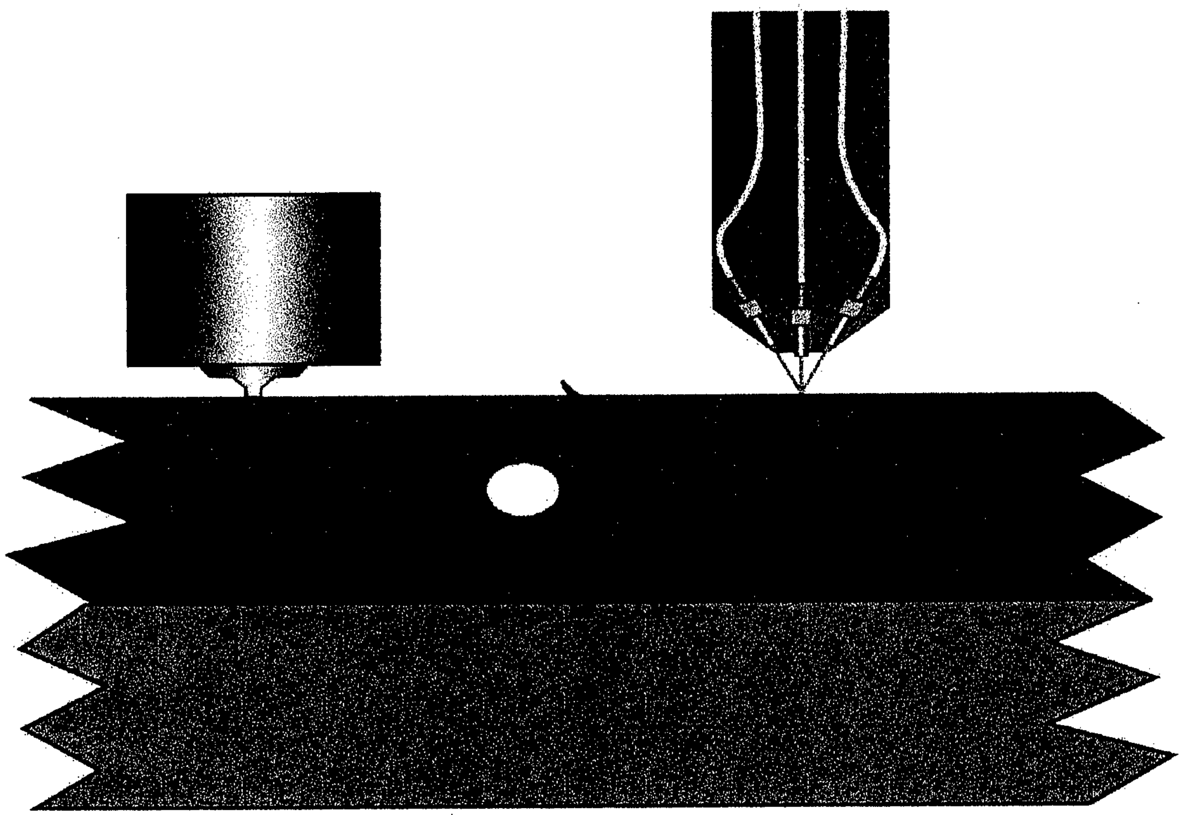

Figure 1 Basis Experimental Set-up

and (2) to accurately determine the complex sound speeds by a least square fit of the model prediction to experimental data. The complex sound speeds are the input parameters in the least squares fit. This method was tested using a simpler attenuated-ray model based on geometrical acoustics. The results were good, with the least squares sound speed values within 5 percent of the values determined by conventional methods. Simplified test cases of the problems at hand were performed to validate fundamental methods beings used in the numerical models.

To quantify the reproducibility of data taken with the system, an experiment was conducted in which a typical set of data was taken and then the system was shut down. The system was restarted 24 hours later and the data set repeated. By analyzing

the differences in the data, an absolute data repeatability margin of 2.5nm (5% of the surface displacement) was determined. See figure 3.

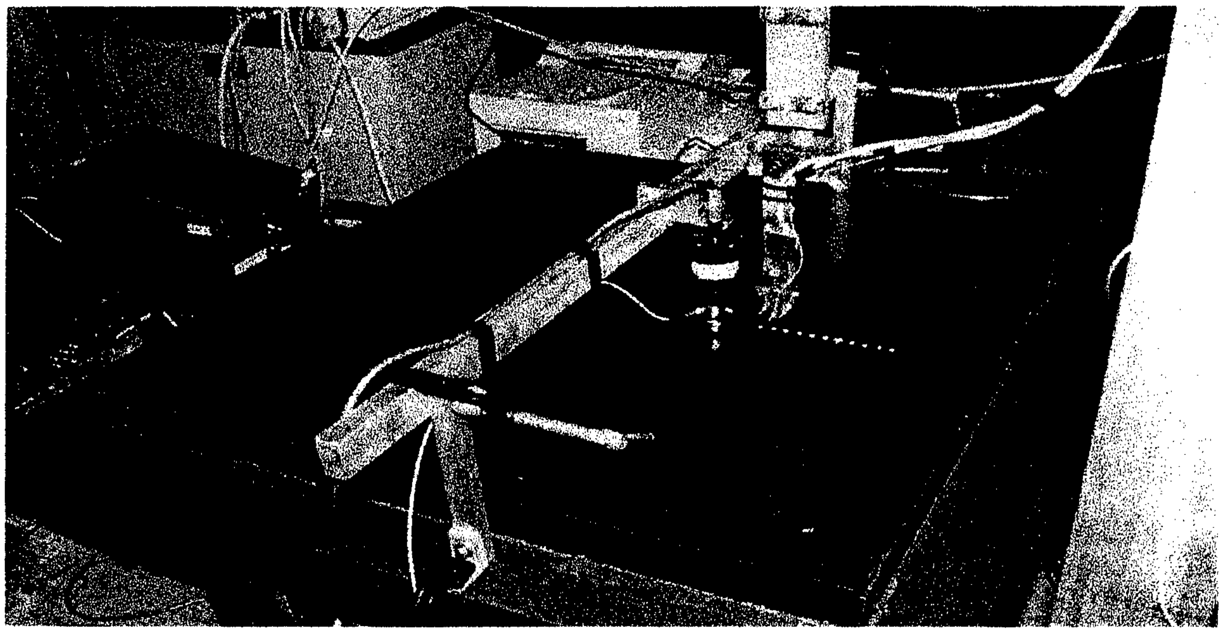

Figure 2 Picture of Experimental test Panel

To reduce the noise floor inherent in the system (largely responsible for the repeatability figure), significant hardware upgrades were initiated. Principal among these were conversion to a more powerful argon-ion laser source and implementation of a next generation probe head with improved light focusing and alignment. The consequences of these upgrades will be a stronger reflected signal off of a given source and a more stable measurement platform, improving stability and lowering the noise floor.

At this point, the current state of research was reported at an ONR Structural Acoustics program review held in Austin, Texas (Feb 18-21, 1997).

<u>April 1997 - present</u>

Another area for improving the signal quality is the input source. Two shakers, a B&K 4810 and a Wilcoxon F7, had been used up this point. In an effort to improve drive level (and have a dedicated source) some work was done on converting a piezo-electric flex-disc driver for the *in-situ* application. This proved to be unsuitable for desired application and was abandoned when purchase of a B&K 4810 was authorized.

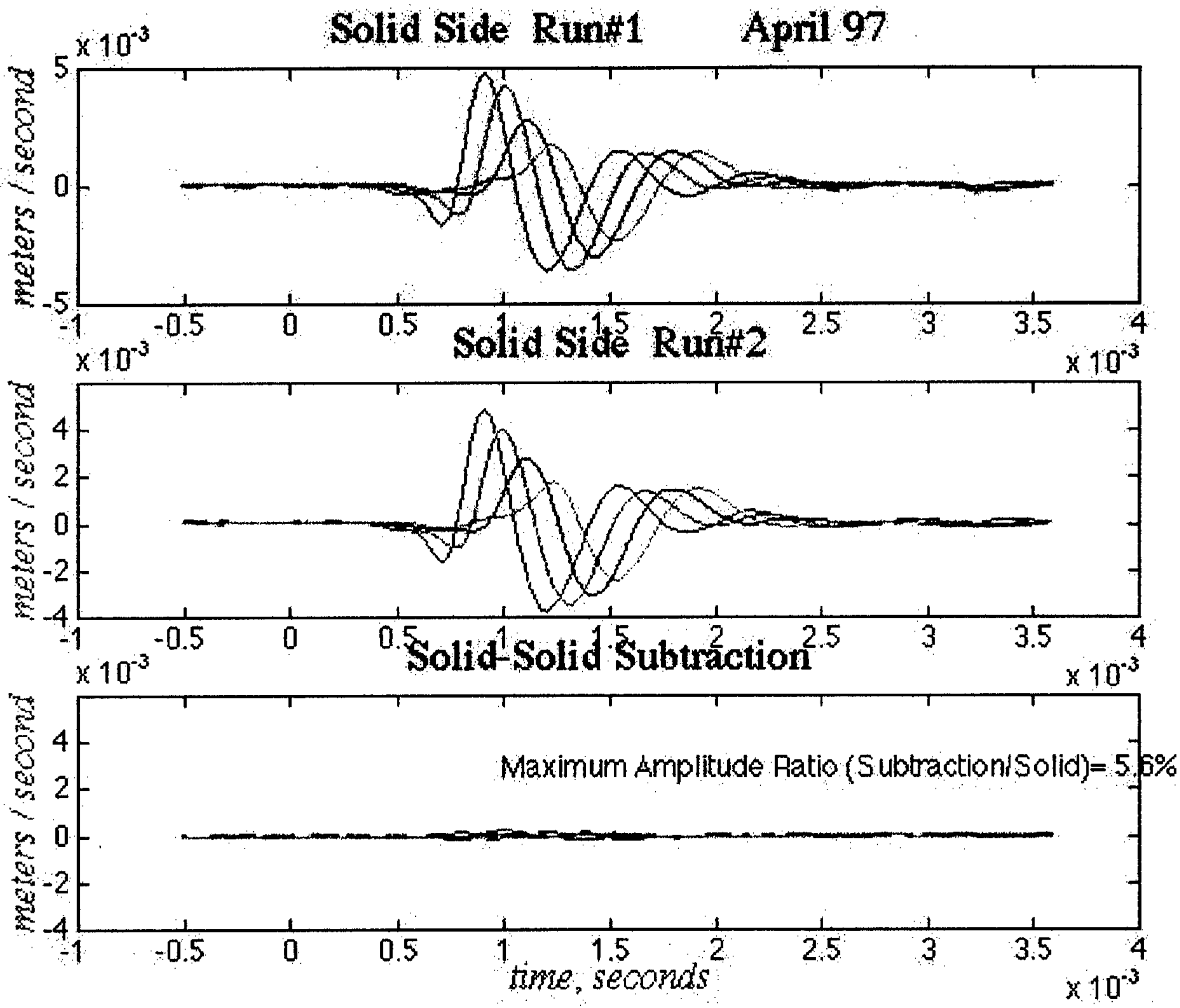

Figure 3 Measurement Repeatability

In response to an associated area of concern, namely air bubbles, a first-look experiment was conducted to test the feasibility of using this LDV system package for detecting bubbles embedded in a SHT panel. To do this a thin strip of the SHT material was mounted on a steel bar, to replicate the full size panel conditions, and a 1/4" hole drilled through its thickness. Figure 4 illustrates the test strip. Subsequent LDV measurements and minimal analysis showed that the presence of the cavity manifested itself in the surface velocity data and is indicated in figure 5. A SARA 2D finite element analysis was used for a parameter study to determine the minimum size bubbles versus depth that could be detected using the experimental noise floor. Further analyses of the observed phenomena are anticipated.

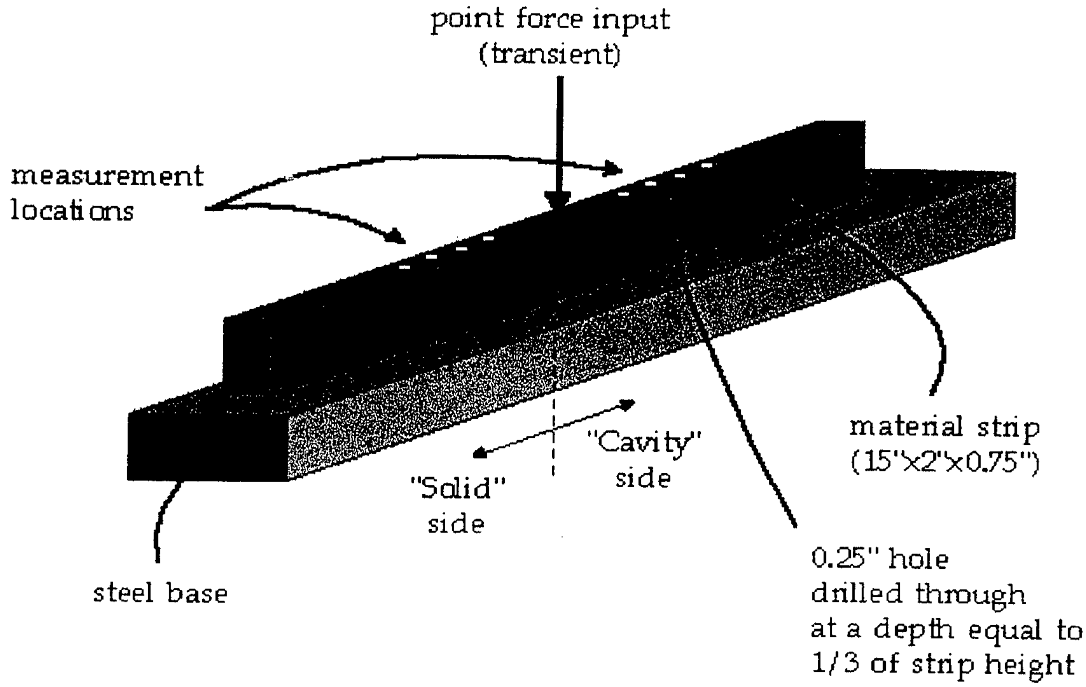

Figure 4 Experimental Set-up for Cavity Detection

Efforts to develop an exact, physics-based model based on the Weaver formulation continue.

Hardware improvements continue with the delivery of the next generation probe head. A graduate student is currently being taught the operation of the system and related optics knowledge. The LDV system is being switched to an Argon ion system which should yield a lower noise floor.

5. Planned Work

Work in four major areas is planned: signal processing, modeling, advanced applications, and laboratory/shipyard implementation. First, more sophisticated signal processing techniques are being investigated in order to more precisely extract physical information from the experimental data. In the plans is a chirp signal with a matched filter technique which is designed for analysis and separation of multiple - path signals which contain multiple overlying pulses. Second, need for an exact model is para-mount and significant effort is being devoted to this pursuit. Third, Navy concerns over adhesion and SHT application quality has sparked interest in applying this LDV package to other problems, including the detection of delaminations of the SHT and questionable seam integrity between adjacent strips of SHT as it is applied to

a hull. Finally, the feasibility of applying this method in a shipyard environment and as a laboratory characterization tool will be explored. Discussions with NNSY began in

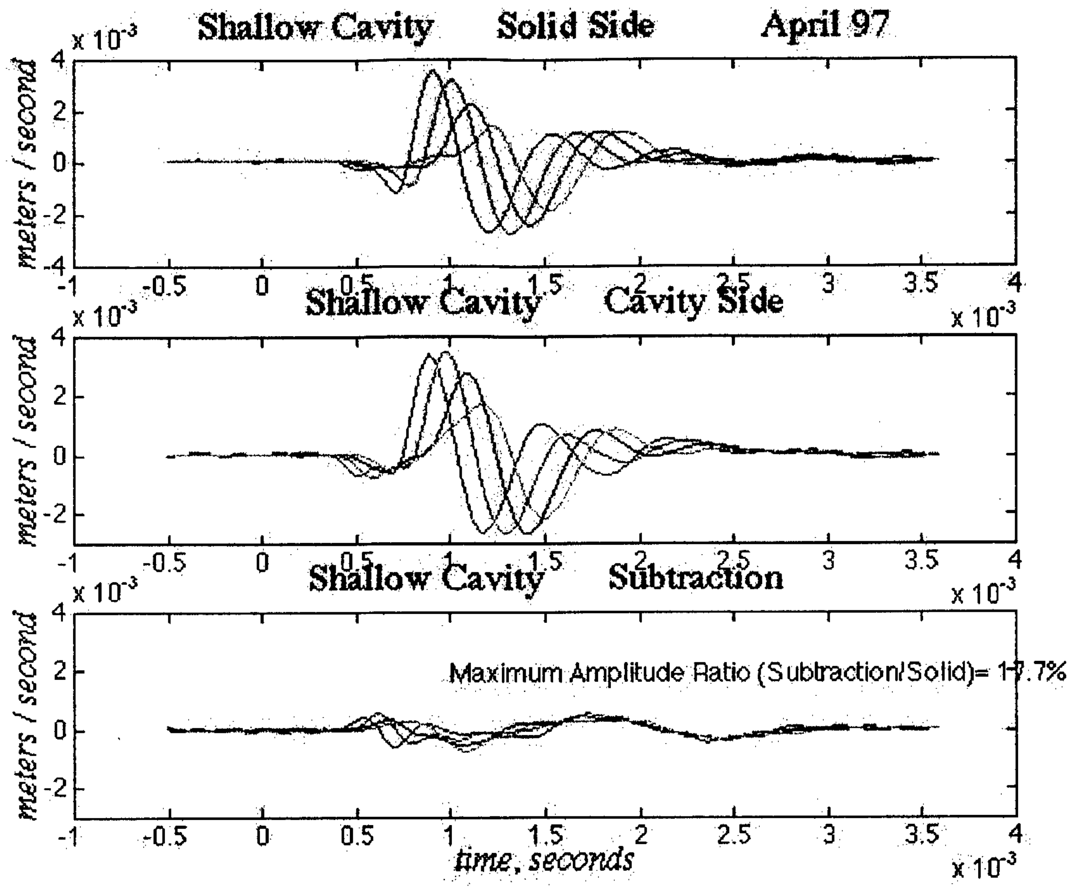

Figure 5 Cavity Detection

September 1997 concerning the industrial applicability and implementation of the method. Specific issues involve identification of the engineering problems and safety concerns associated with a laser based system in the industrial environment. Also the application to characterization of materials from an engineering standpoint will be considered. This approach offers many advantages over other systems or methods being considered for material characterization studies. They include:

1. The method provides the complex longitudinal and shear speeds which give the bulk, K, and shear, G, moduli directly.
2. Provides both moduli, G and K, simultaneously under the same environmental and stress condition.
3. The method makes the measurement over a section of the material so an average value is obtained.
4. The method is noninvasive so there is no loading by the sensors.
5. The method makes the measurement while bonded to a thick flat plate which represents the hull of a submarine. This provides the proper stress state of the

material in the condition that is of interest. (Curvature can be neglected since the thickness to radius of curvature ratio is approximately 0.01.)

Specifically, packaging the system in a controlled pressure and temperature chamber will be investigated.

6. Description of Measurable Performance-Based Milestones

Milestones for this research will include determination of wave speed and attenuation values, within a 2 percent tolerance for wave speeds and 10 percent tolerance for attenuation, from a least squares fit of the data to multiple theoretical models (Fourier transform, finite element). Other milestones will include:

- identification of an inclusion in a prepared test panel.
- identification of delamination in a prepared test panel.
- identification of poor seam quality in a prepared test panel.

Note: These milestones do not depend on knowledge of or an exact model of propagation. They will be evaluated in a semi-empirical manner since all of these phenomena cause perturbation of a "normal or expected" signal or wave pattern. The actual sensitivity analyses will require a more detailed modeling approach.

7. Milestone Chart

FY98 Milestones:

January 1998: Measurement of complex speeds on a coating material bonded to a flat plate in air

March 1998: Detection of air cavities and hard inclusions in coating

September 1998: Start work on detection of weak areas of bonding between coating and metal base and seam integrity evaluation. Complete evaluation of system for shipyard environment and laboratory test bench.

8. Deliverable of FY 1998 Effort

Measurement of complex wave speeds to within a 2 percent tolerance. Development and testing of signal processing procedures for detection of discontinuities such as air bubbles.

9. Transition Plans

Georgia Tech is meeting with NNSY on a continuing basis concerning the feasibility of transitioning the system to a shipyard environment. Secondly Georgia

Tech believes the system can be installed in a pressure vessel and used as a laboratory test bed for the NAVSEA 92RC1 materials evaluation program.